EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

INTENT
CERN/LEPC/82-60
LEPC/I3 Add. 2
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SUBMITTED BY THE L3 COLLABORATION TO THE LEPC

We are pleased to report that the following institutions have joined our collaboration:

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We report here our efforts to improve our detector, following the instructions from the directors of CERN on 15 July 1982.

These instructions were to

a) improve the hadron calorimeter;
b) increase the magnetic field in the central detector;
c) reduce the size of the magnet so that it will fit into a standard-size hall.

We have followed these recommendations carefully, and have intensively studied the implications of these suggestions. This report concerns the modifications of our detector accordingly.

1. HADRON CALORIMETER

Much effort has been spent on optimizing the calorimeter design. Because of the space available in our detector, we have enlarged the calorimeter volume by up to a factor of 1.8 for this purpose.

We consider a sampling calorimeter design with depleted uranium and copper as absorption material, and a gas detector operating in limited streamer mode as read-out planes[1)].

1.1 Design considerations

The design considerations for the improved hadron calorimeter can be summarized as follows:

i) to achieve the best possible energy resolution;
ii) to optimize spatial resolution by a high-granularity tower structure matching the BGO segmentation and pointing towards the intersection region;
iii) a minimum of seven absorption lengths (with BGO) for very high muon-to-hadron separation;
iv) muon tracking within the calorimeter, thereby achieving the ability to identify and measure the range of low-energy muons.

1.2 Properties of the calorimeter

In order to fulfil these design considerations, our new calorimeter has the following properties:

i) As an absorber we intend to use a Cu/U/Cu sandwich (2/4/2 mm). The energy resolution of the hadron calorimeter should improve considerably owing to the energy compensation properties of uranium.
ii) Fine-grained sampling for the first four absorption lengths; the number of sampling planes will be increased by at least a factor of 3, from 20 planes to at least 60 planes. This results in an increase in the outer radius of the calorimeter by 20 cm. We expect an energy resolution of $0.45/\sqrt{E}$ as compared to the original value of $0.75/\sqrt{E}$. These numbers are based on data measuring the resolution as a function of plate thickness (Fig. 1). Figure 2 shows the general layout of the improved calorimeter compared to the original design.
iii) We divide the solid angle (96% of 4π) via capacitively coupled readout pads, into 3000 elements, each corresponding to a 2×2 array of the BGO crystals, and pointing to the vertex. This represents a factor of 2 improvement in spatial resolution over the original design of 1400 tower elements. Figure 3 shows schematically the pad arrangement matching four BGO crystals. In addition to the pad readout, we will record the hit pattern of the wires to

trace isolated muons inside the calorimeter. We expect a muon-to-hadron separation of better than 1/1000.

iv) We reserve an additional 20 cm of radial space for possible future improvements. In summary, these modifications may enlarge the calorimeter volume by up to a factor of 1.8 and reduce the measured muon track length by 40 cm.

Table 1 lists the properties of the improved calorimeter as compared with the original design.

Table 1

Hadron calorimeter parameters

	Letter of Intent	Improvement
Total radial length (cm)	114	128
Inner/outer radius (cm)	80/200	82/220(240)
Absorption length of fine-grained structure + BGO	4.5	4.5
Absorption length of muon filter	2.5	2.5
Absorber material of fine-grained structure	Cu (20 × 25 mm)	Cu/U/Cu, 60 × (2/4/2 mm)
Absorber material of muon filter	Cu (3 × 120 mm)	Cu (3 × 120 mm)
Number of sampling planes in fine-grained structure	20	60
Muon tracking planes	23	63
Punch-through fraction	1/1000	1/1000
Solid angle (of 4π)	0.96	0.96
Spatial resolution (electronic towers)	1400	3000
Matching BGO elements	3 × 3	2 × 2
Energy resolution	$0.75/\sqrt{E}$	$0.45/\sqrt{E}$

Table 2 gives the corresponding cost estimate of the electronics part of the calorimeter assuming that all tubes are read out.

Table 2

Hadron calorimeter read-out cost estimate

Item	Letter of Intent	Improvement
No. of electronic towers	1400	3000
No. of ADC channels	2800	6000
Analog read-out ADC channels	0.225 MSF	0.480 MSF
Digital read-out for muon range and tracking	0.950 MSF	2.717 MSF
Chamber + gas container + pads, etc.		
- fine-grained part (with pads)	0.375 MSF	1.125 MSF
- muon part (without pads)	0.038 MSF	0.046 MSF
TOTAL	1.588 MSF	4.368 MSF
Increase	2.780 MSF	

1.3 Tests

Before construction, the following tests will be made:

i) The uranium compensation effect has been shown to work for calorimeters using either a liquid-argon ionization chamber[2)] or scintillator plates[3)] as the sampling detector. But both the detector density and the cut-off energy are different in the case of gas sampling planes.

ii) The contribution of the uranium radioactivity to the over-all r.m.s. noise[4)] will be checked by comparing copper and uranium absorber plates in a prototype. The noise will be measured as a function of the shielding material thickness.

iii) Independently of the nature of the absorber material, detector planes operating in the limited streamer mode were, up to now, only occasionally used for energy measurement[5)]. Further studies have to be performed to obtain the contribution of these types of sampling detectors to the over-all energy resolution, and to find optimum working conditions as a function of gas mixture and cell size.

In order to perform the program outlined above, test set-ups have been constructed both at CERN and ITEP (Moscow).

1.3.1 *CERN test set-up*

We have built a test prototype as outlined in Ref. 1, consisting of 46 layers of drift tubes of the type used in the Mont Blanc experiment[6]. The test set-up is shown in Fig. 4. Two types of absorbers are going to be used: copper plates (12 mm thick), and Cu/U/Cu sandwiches (Fig. 5). The performance of the prototype with Cu absorber is now being studied in the t_6 test beam at the PS. The determination of the energy resolution is the immediate goal.

1.3.2 *ITEP test set-up*

Another prototype using triangular drift tubes has been built at ITEP (Fig. 6). The limited streamer mode will be systematically studied, comparing it with proportional and saturated avalanche modes. We also want to check ageing effects. The test is now in progress at the 10 GeV ITEP proton synchrotron.

1.3.3 *Tests with radioactive sources*

We have started a systematic study of the performance of various types of drift tubes with radioactive sources. The tests are in progress both at CERN and ITEP. The objectives are to find the minimum tube size which works reliably in the limited streamer mode, to find a gas mixture which ensures a wide high-voltage plateau, and to study the ageing characteristics.

2. MAGNETIC FIELD INCREASE IN THE CENTRAL DETECTOR

As will be described, with the new magnet design the field in the central detector has increased, by 13%, to 5.1 kG.

3. REDUCED SIZE OF THE MAGNET

In choosing the size of the magnet, we have taken the following into account:

A) Muon pair mass resolution. Since muon production angles are measured accurately by the vertex chamber, both inclusive muon and multimuon resolutions are determined by the muon momentum measurements. It is important to note that the effective track length (L), as measured in the muon chamber, is much shorter than the available radius of the magnet (R). The original L3 design has a total radius of 6.0 m, but 2.0 m are used by the calorimeters, and 0.30 m is needed for drift chambers (the average wire position determines the effective radius of the measurements), leaving only 3.70 m as the effective lever arm for measuring the muon momentum.

In a 4.5 kG field and for a 50 GeV muon the sagitta is 4.7 mm and is proportional to L^2. For this case the chamber resolution will allow a 1.5% determination of momentum with 0.6% error from multiple scattering and 0.6% from alignment. (We note that the first contribution dominates, and the latter two essentially will not change under radius reduction.) Treating the contribution as uncorrelated, we arrive at the mass resolution of 1.2% for muon pairs (Fig. 7) as given in the L3 Letter of Intent, Addendum 1.

B) With input power and coil constant, decreasing the radius leads not only to higher magnetic field but also to thicker return yoke iron, partly compensating the reduction of R. After intensive study with Dr. F. Wittgenstein, Mr. M. Harris of CERN, and Mr. J. Tarrh, senior engineer at the Frances Bitter National Magnet Laboratory, USA, we propose an over-all diameter reduction of 80 cm and over-all length reduction of 90 cm, and to reduce the amount of iron by 1000 tons.

Since the expanded calorimeter may take up between 20 cm and 40 cm of radial space, the total reduction of the effective muon track length is between 60 cm and 80 cm, leaving the effective muon track length between 3.10 m and 2.90 m, compared to 3.70 m in the original design. This changes the muon fiducial volume by 1/3 and reduces the muon pair mass resolution to between $(3.70/3.10)^2 = 1.4$ and $(3.70/2.90)^2 = 1.6$.

C) The field homogeneity versus peak field was studied by varying the magnet parameters and constraining the power consumption to a maximum of 4 MW. This led to a magnet design (Fig. 8) with the following parameters:

magnetic field	= 0.51 tesla
weight of iron	= 6600 t
weight of aluminium	= 1000 t
power required	= 4 MW
current required	= 30 kA

The combined effect of reducing the magnet size and increasing the central field is a degradation of the muon pair mass resolution dm/m to between 1.3% and 1.7% at 90 GeV.

D) Our efforts to reduce the material and manufacturing costs of the basic elements of the magnet have reached the following stage.

Materials: Our request to obtain

i) 8000 tons of steel bars ($13 \times 13 \times 1200$ cm^3),
ii) 1000 tons of aluminium plates (thickness 6 cm), and
iii) 400 tons of copper plates for the hadron calorimeter

as a loan from the Swiss government has passed smoothly through all Swiss government agencies with strong support. The final formal authorization by the Swiss Bundesrat is expected favourably in three weeks' time.

The Foreign Affairs Department of Switzerland has informed us that they expect no difficulties in using these materials at LEP, which is mainly located in France.

Manufacturing: To reduce the costs, we have held workshops with engineers of CERN, the Von Roll Company at the Bodio Plant and the Gerlafingen Plant (Switzerland), and engineers from the Frances Bitter National Magnet Lab., USA. These studies show that we can use extruded steel bars (which are input to rolling mills) as the return yoke and endcaps with a minimum amount of welding.

We have also had many joint studies with the Sciaky Company in Paris and with the CERN Central Mechanical Workshop with a view to using electron beam welding (a standard industrial technique) for our steel and aluminium. This will reduce the manufacturing costs significantly, and also increase the quality of the joints.

After discussion with the Alusuisse Company at Zurich and Chippis (Switzerland) we plan to use standard industrial plates to construct the coil.

The new magnet construction, with reduced size, will cost much less than the original design, as itemized in Table 3.

Table 3

L3 magnet cost estimates

Item	MSF
Iron	(3.3)
Aluminium	(2.4)
Structural material	(0.9)
Fabrication	4.0
Welding	2.0
Transportation	0.5
Assembly	6.0
Engineering, design, power supply, cooling, etc.	6.7
Total	19.2 (25.8)

The magnet now costs 19.2 MSF with borrowed materials and 25.8 MSF with purchased materials. This compares with the original value (26 May report) of 36.6 MSF.

E) Dr. Franco Bonaudi has confirmed that this magnet can fit into a rotated, standard-size experimental hall. A detailed study has been made[7].

F) It is important to note that the central field is determined mainly by the coils; the addition of the iron increases the total field by 1/3. The main function of the iron is to homogenize the field in the useful volume, and to reduce the stray field which could influence the operation of the system. The main cost of the magnet is the manufacturing, assembly, etc., as seen from the table. Further reduction of iron and aluminium will not reduce the cost significantly.

4. SUMMARY

a) We have improved the hadron calorimeter design. We can enlarge the calorimeter volume by a maximum factor of 1.8, taking up to 40 cm more of the available radius for this purpose. The energy resolution has improved from $0.75/\sqrt{E}$ to $0.45/\sqrt{E}$. The cost of the calorimeter has increased by 2.8 MSF.

b) We have reduced the magnet diameter by 80 cm, the length by 90 cm, and the amount of iron by 1000 t. We have changed the effective magnetic volume by 1/3.

c) We have increased the magnetic field in the central detector by 13%.

d) The combined effect of increasing the calorimeter volume, increasing the magnetic field, and reducing the magnet size could result in the degrading of the muon pair mass resolution dm/m to 1.7%. Figure 9 shows the rapid deterioration of resolution which will arise from any further decrease in the size of the magnet.

e) By using new methods of construction, we have reduced the cost of the new magnet design by nearly a factor of 2. This magnet will fit into a rotated standard size experimental hall.

REFERENCES

1) L3 Collaboration: Letter of Intent, 22 January 1982, and CERN/LEPC/82-45/I3 Add. 1, 30 June 1982.

2) C.W. Fabjan et al., Nucl. Instrum. Methods 141 (1977) 61.

3) O. Botner, Phys. Scripta 23 (1981) 556.
O. Botner et al., IEEE Trans. Nucl. Sci. NS-28 (1981) 510.

4) P. Spillantini, LNF-82/24 (NT) (1982).

5) M. Jonker et al., Phys. Scripta 23 (1981) 677.
G. Battistoni et al., LNF-82/16 (P) (1982).
M. Atac et al., Fermilab report FN-337, April 1981.

6) Frascati-Milan-Turin Collaboration, Proposal for a Nuclear Stability Experiment (1979), unpublished.

7) F. Bonaudi, private communication.

Figure captions

Fig. 1 : Energy resolution for hadron calorimeters as a function of absorber plate thickness for different absorber materials.

Fig. 2 : General layout of the hadron calorimeter (end view), showing some details of the fine-grained structure. The broken line shows the additional 20 cm space for possible future improvements. Also shown, for comparison, is the original design.

Fig. 3 : Structure of an electronic tower formed by the readout pads and four matching BGO crystals. The streamer tube readout for muon tracking is indicated.

Fig. 4 : Schematic view of the test set-up used at CERN.

Fig. 5 : Sketch of the Cu/U/Cu absorber structure foreseen for the CERN tests.

Fig. 6 : Schematic view of the ITEP test set-up.

Fig. 7 : Properties of the original L3 detector with regard to the muon analysis.

Fig. 8 : Schematic magnet design.

Fig. 9 : The effective mass resolution, dm/m in %, of the modified L3 detector, as a function of the radius and the effective track length as measured by the muon chambers. The space allocated for the calorimeters and chambers is also indicated.

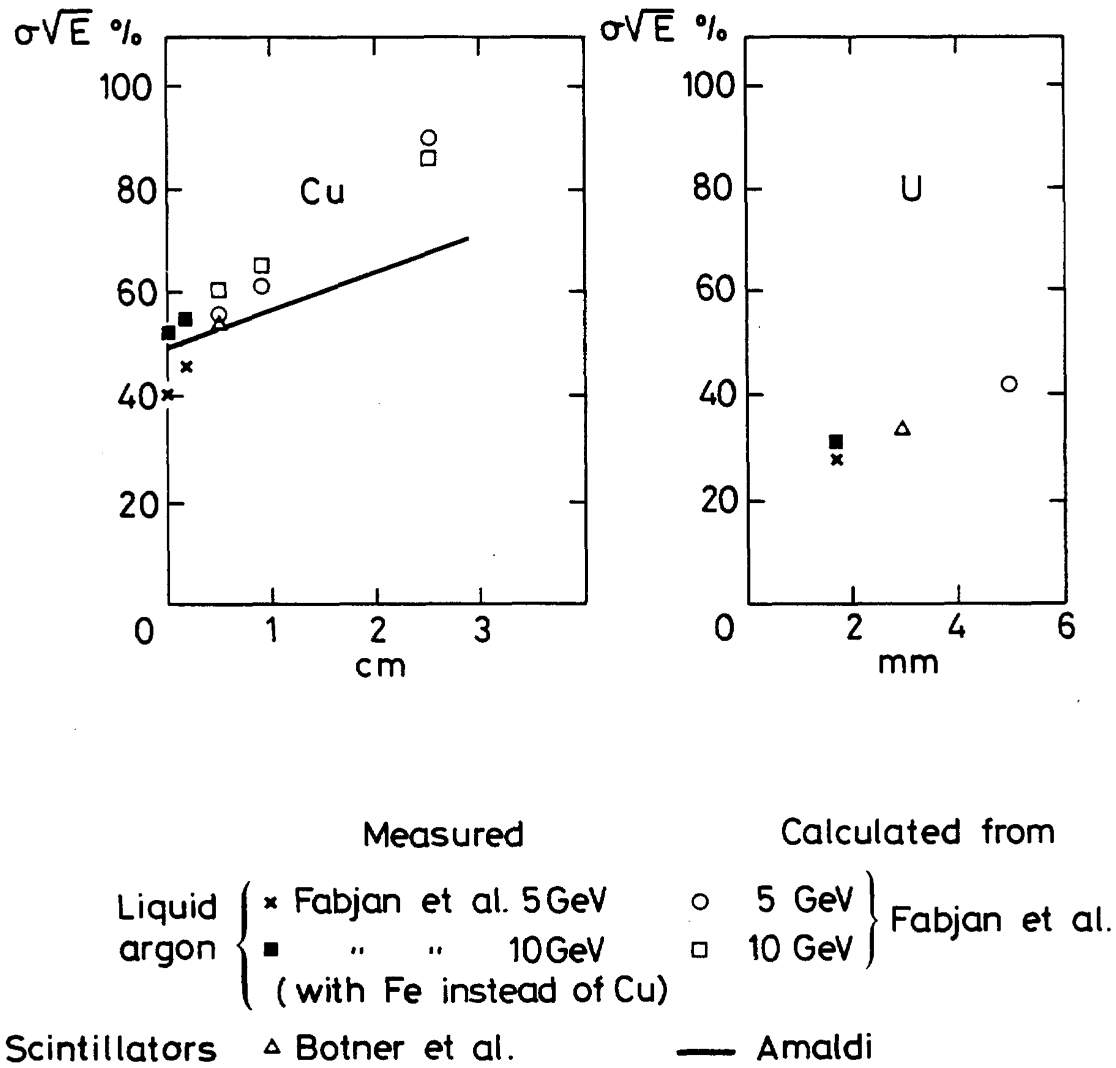

σ√E %
100
80
60
40
20
0
1
2
3
cm
Cu
σ√E %
U
2
4
6
mm
Measured
Calculated from
Liquid argon
× Fabjan et al. 5 GeV
■ " " 10 GeV
(with Fe instead of Cu)
○ 5 GeV
□ 10 GeV
Fabjan et al.
Scintillators
△ Botner et al.
Amaldi

Fig. 1

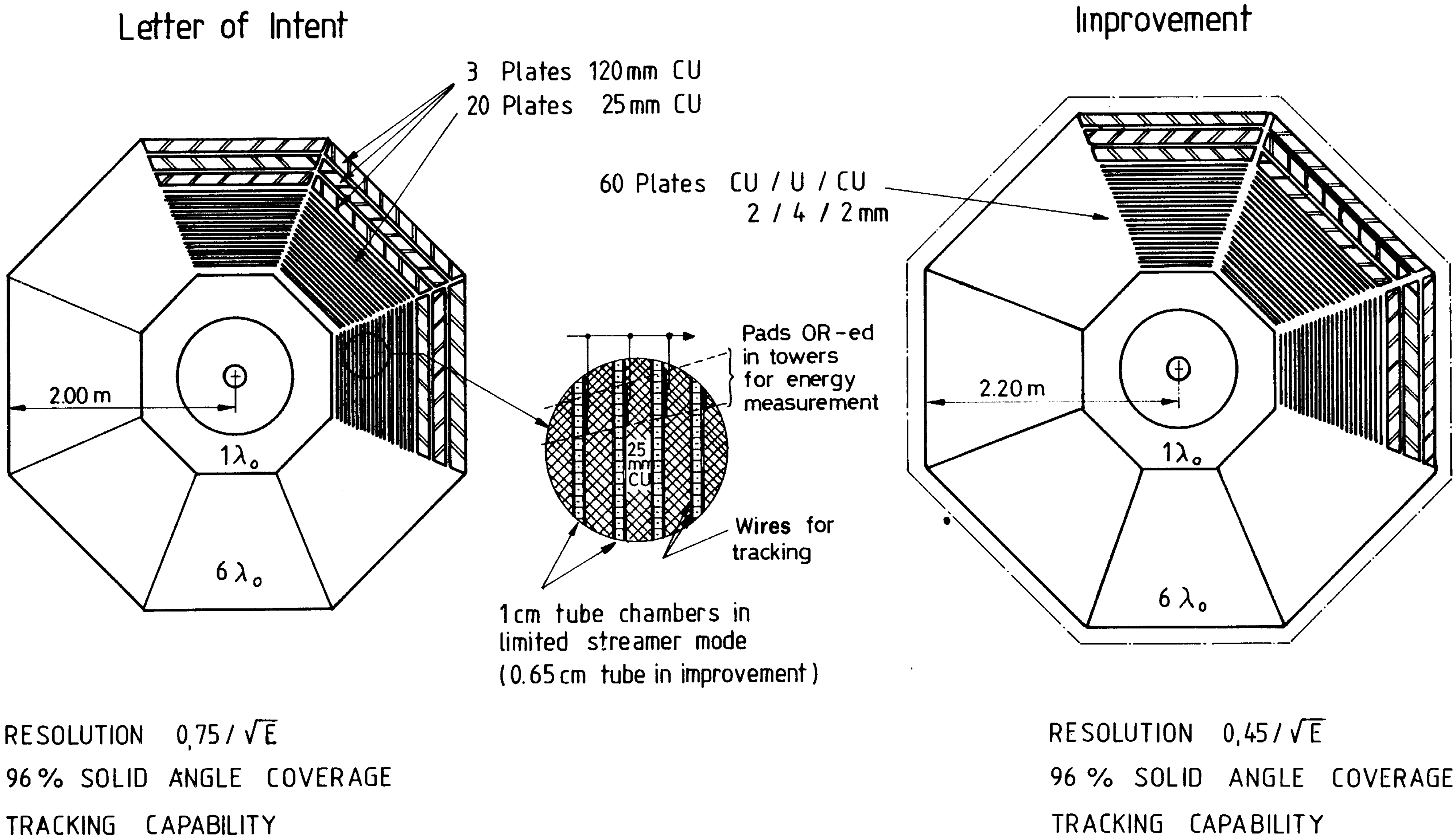
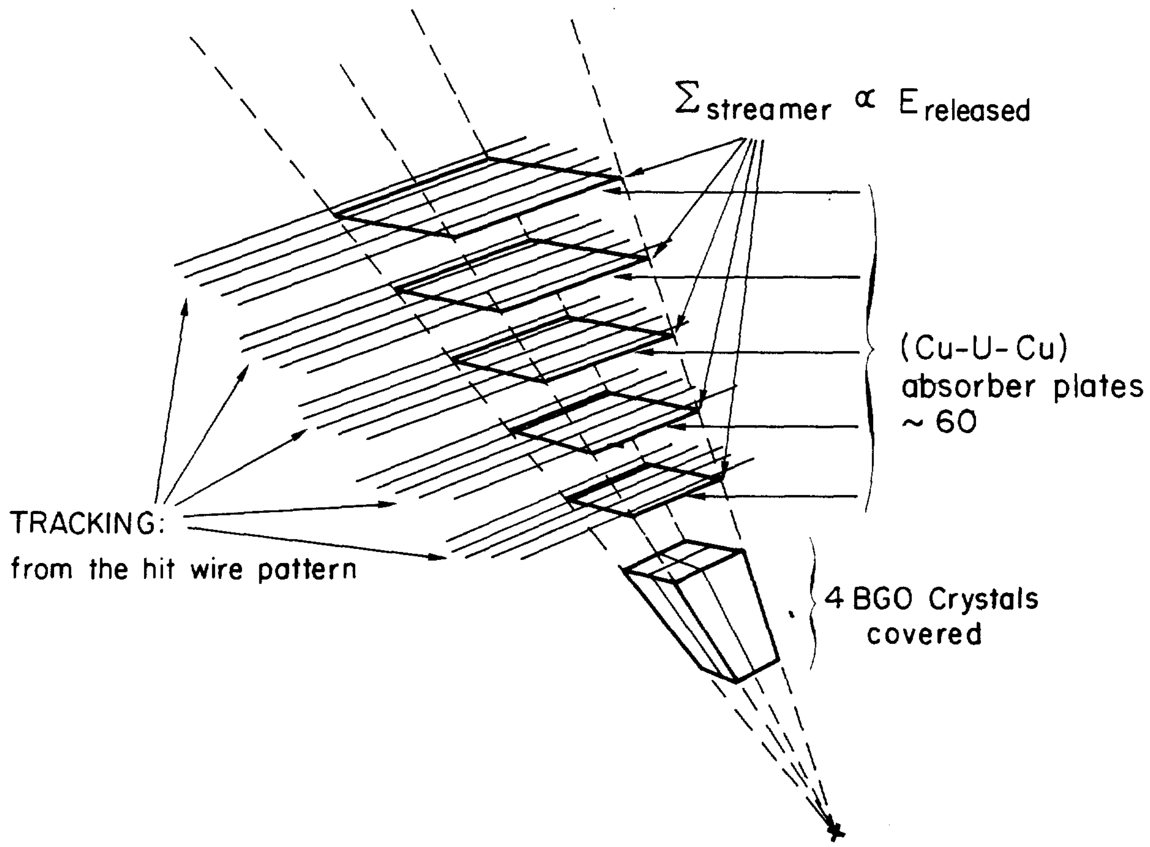

Letter of Intent
Inprovement
3 Plates 120mm CU
20 Plates 25mm CU
60 Plates CU / U / CU
2 / 4 / 2mm
2.00 m
$1\lambda_o$
$6\lambda_o$
Pads OR-ed
in towers
for energy
measurement
25 mm CU
Wires for
tracking
1cm tube chambers in
limited streamer mode
(0.65cm tube in improvement)
2.20 m
$1\lambda_o$
$6\lambda_o$
RESOLUTION 0,75 / √E
96% SOLID ANGLE COVERAGE
TRACKING CAPABILITY
RESOLUTION 0,45 / √E
96 % SOLID ANGLE COVERAGE
TRACKING CAPABILITY

Fig. 2



$\Sigma_{streamer} \propto E_{released}$
(Cu-U-Cu)
absorber plates
~ 60
TRACKING:
from the hit wire pattern
4 BGO Crystals
covered

Fig. 3

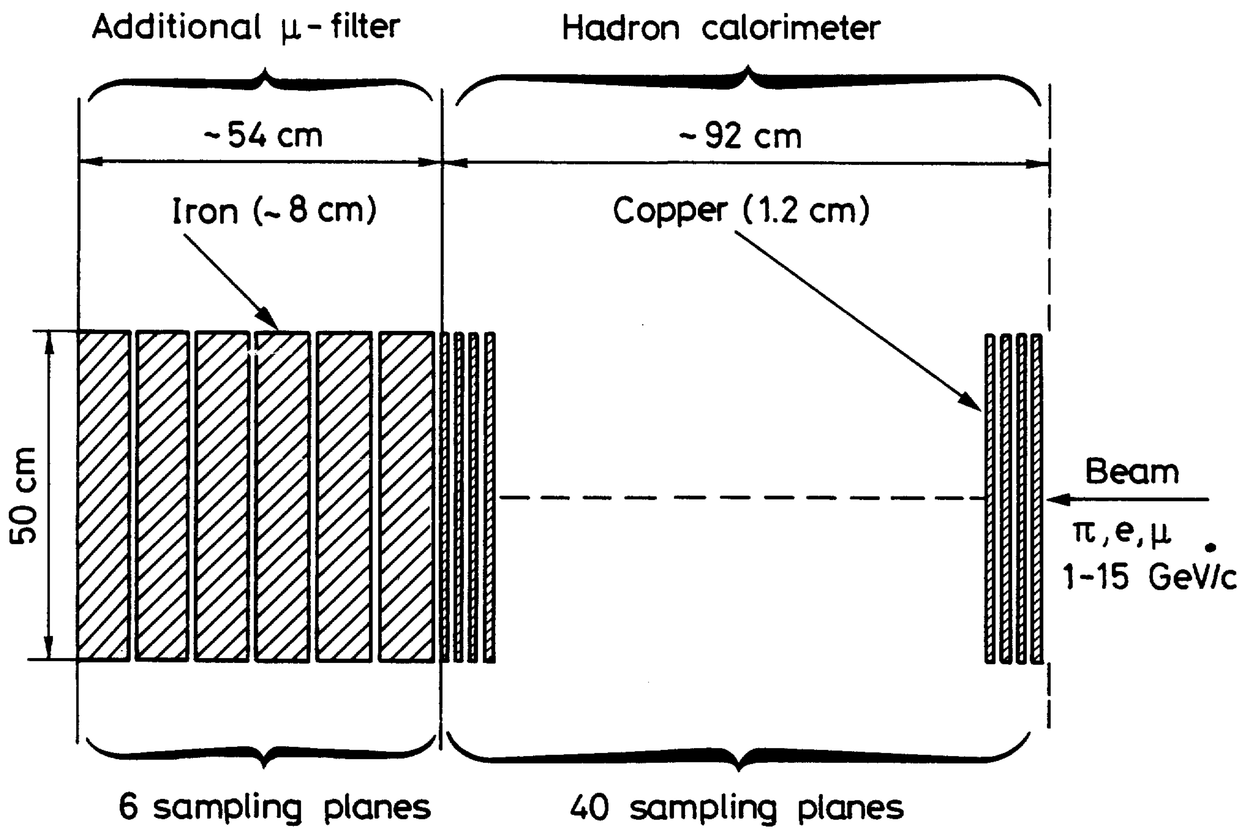

Additional μ - filter
Hadron calorimeter
~ 54 cm
~ 92 cm
Iron (~ 8 cm)
Copper (1.2 cm)
50 cm
Beam
π, e, μ
1-15 GeV/c
6 sampling planes
40 sampling planes

Fig. 4

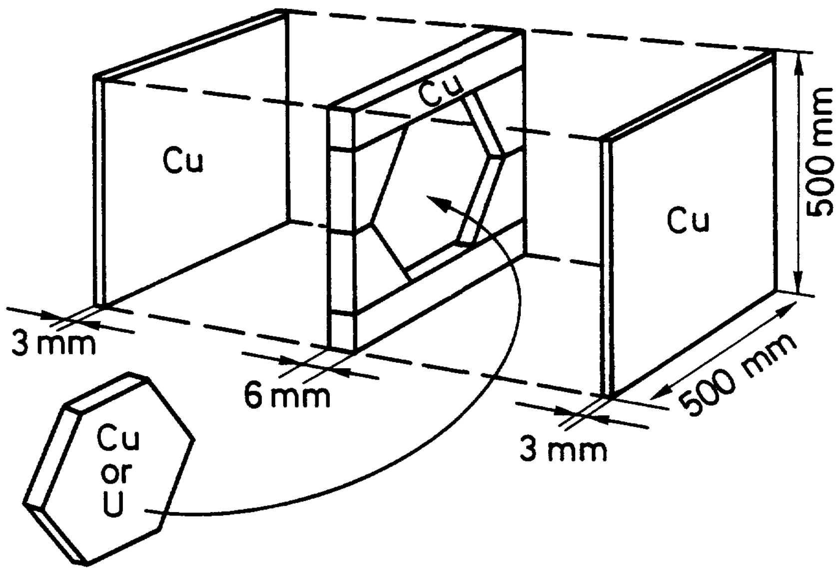

Cu
Cu
Cu
500 mm
3 mm
6 mm
3 mm
500 mm
Cu
or
U

Fig. 5

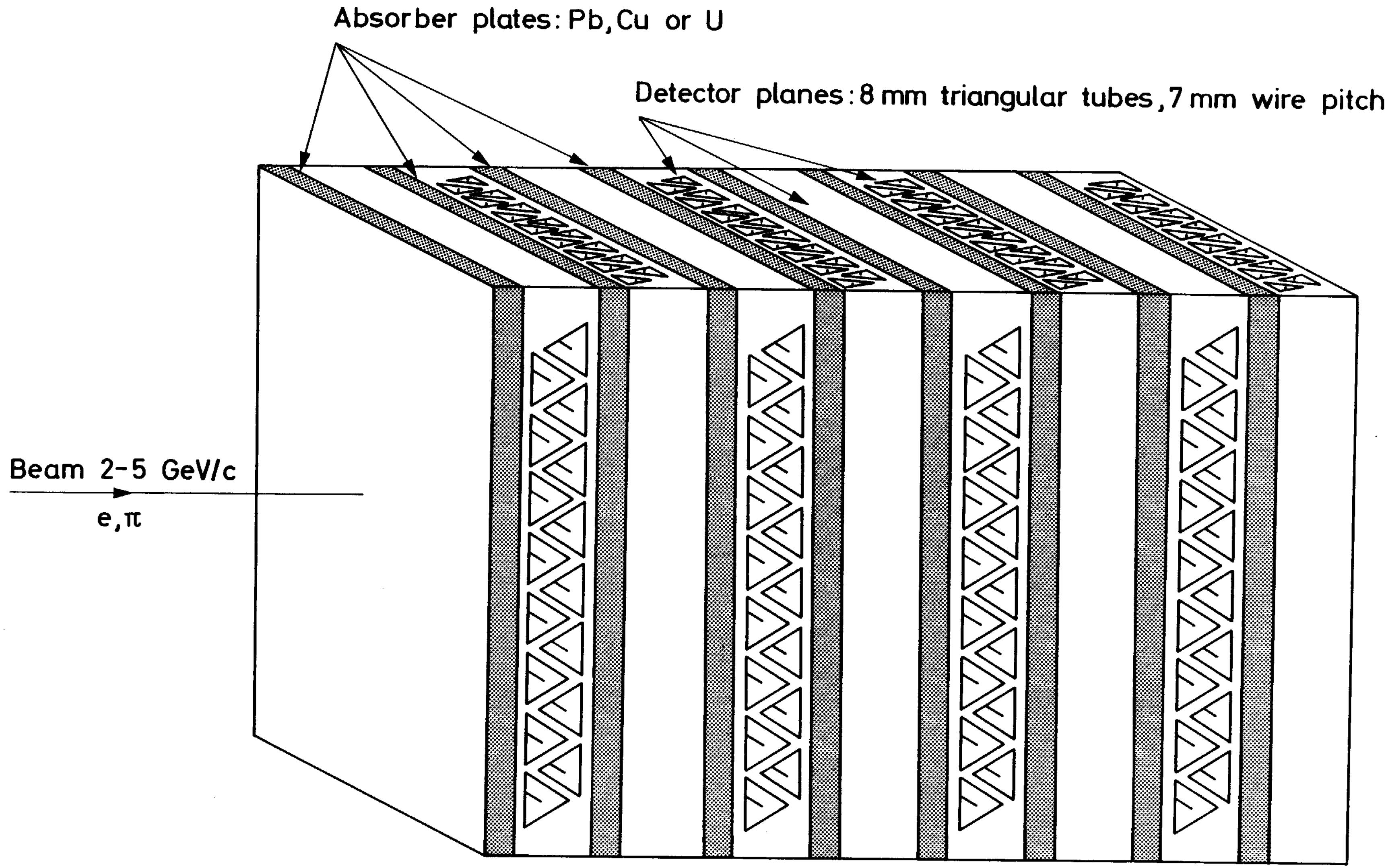
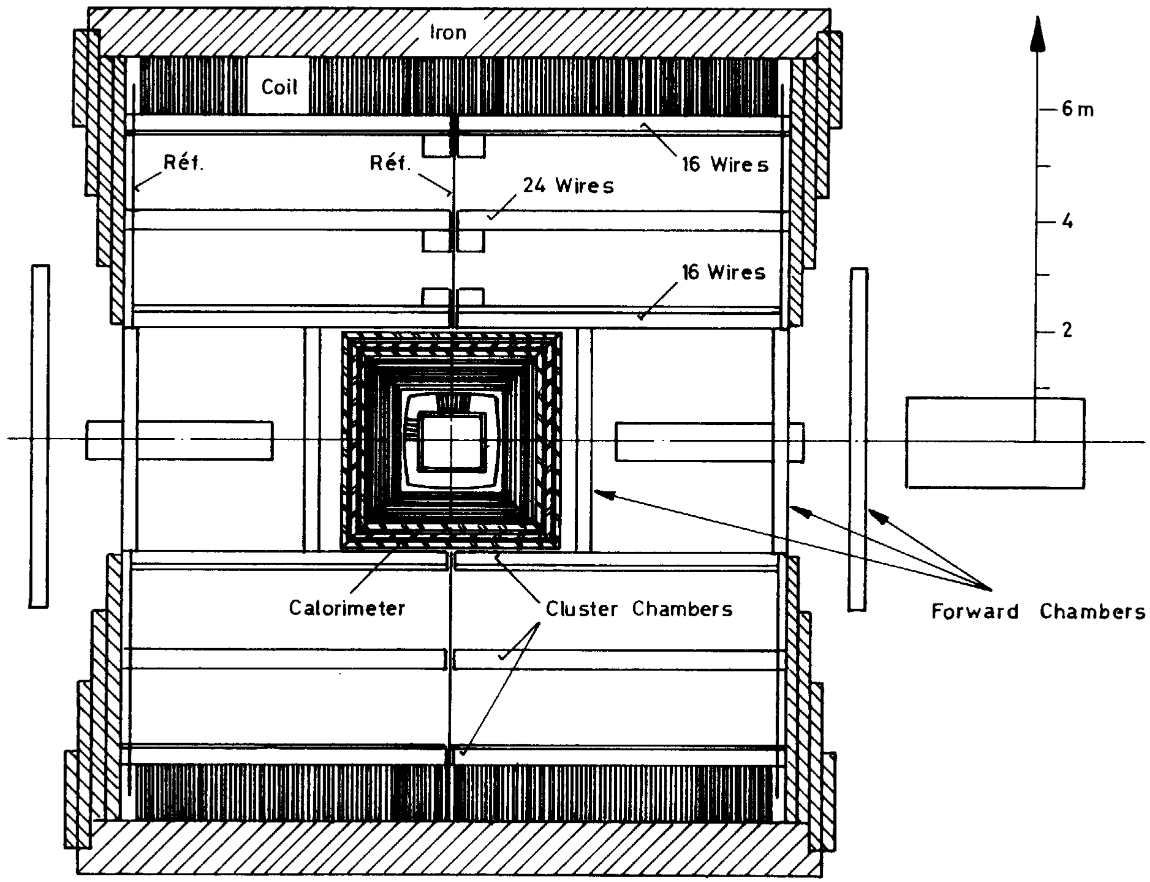
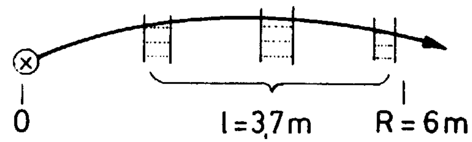

Absorber plates: Pb, Cu or U
Detector planes: 8 mm triangular tubes, 7 mm wire pitch
Beam 2-5 GeV/c
e, π

Fig. 6



The L3 detector with forward muon chambers.



4,5 kΓ $\quad s = l^2/8\rho = 4700\,\mu m$

$\Delta s/s = 1{,}5\,\%$ chamber
$+\ 0{,}6\,\%$ mult. s.
$+\ 0{,}6\,\%$ system.

$$\frac{\Delta m}{m} = \frac{1}{\sqrt{2}}\,\frac{\Delta p}{p} = \frac{1}{\sqrt{2}}\,\frac{\Delta s}{s} = 1{,}2\,\%$$

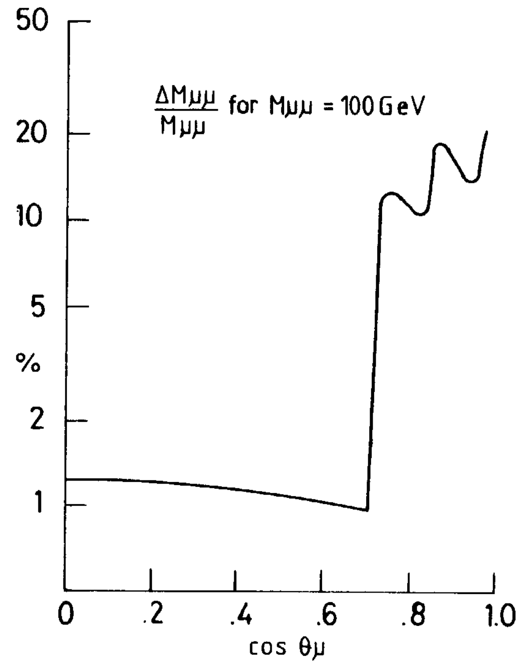
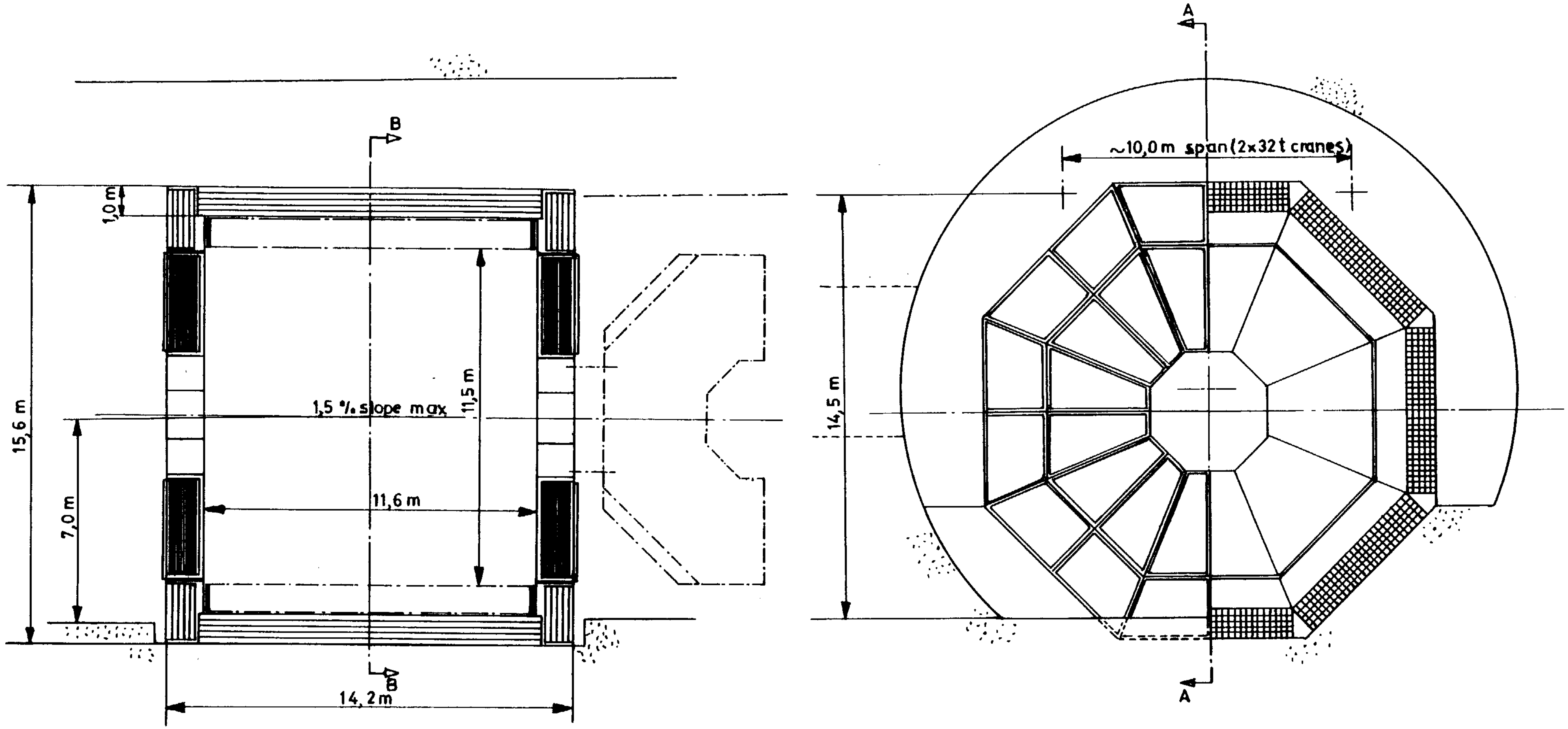


Fig. 7



Section A-A

Half End View Half Section B-B

Fig. 8

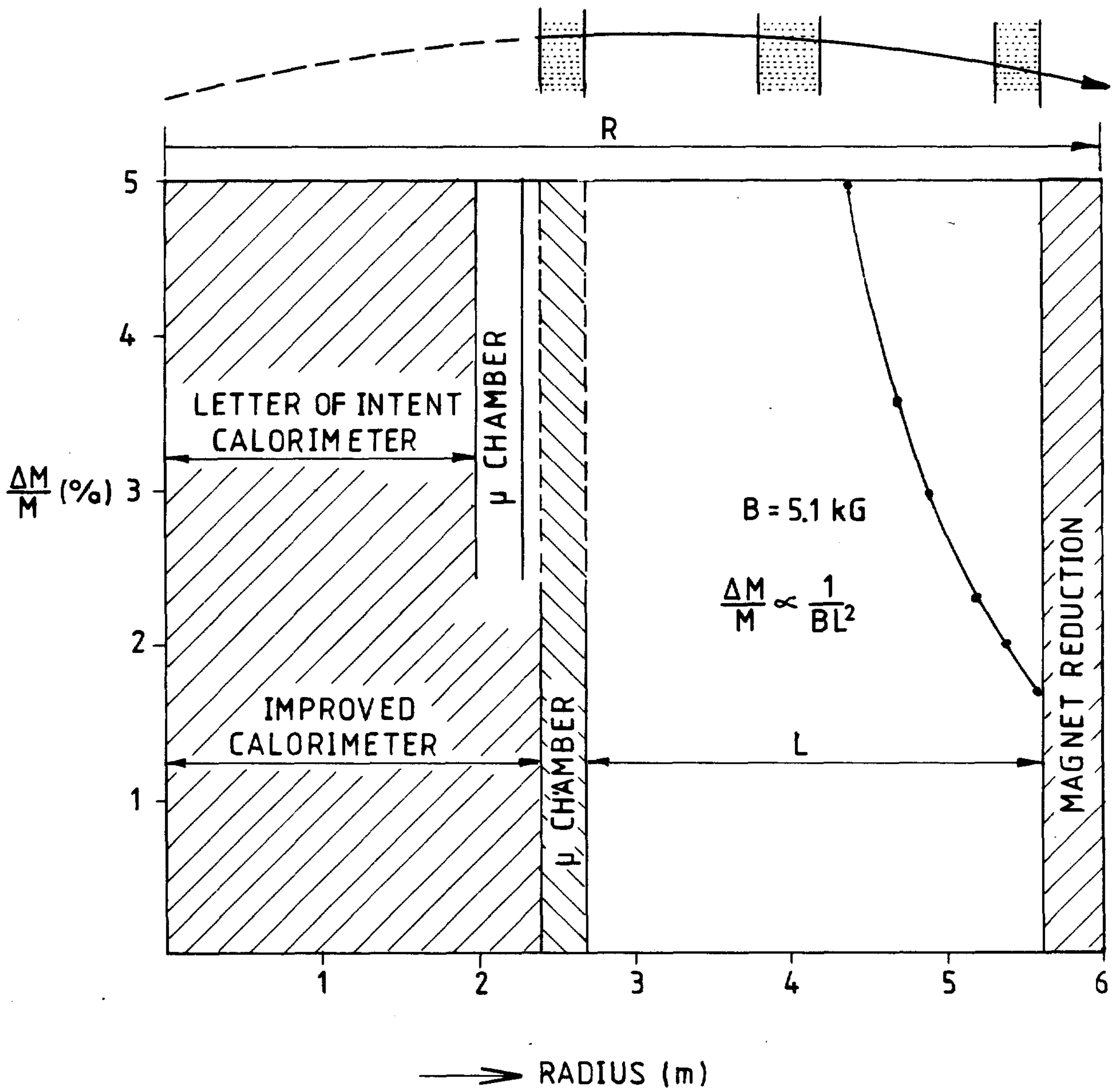

R
LETTER OF INTENT
CALORIMETER
μ CHAMBER
IMPROVED
CALORIMETER
μ CHAMBER
B = 5.1 kG
$\frac{\Delta M}{M} \propto \frac{1}{BL^2}$
L
MAGNET REDUCTION
$\frac{\Delta M}{M}$ (%)
5
4
3
2
1
1
2
3
4
5
6
RADIUS (m)

Fig. 9